CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

Furnaces and boilers represent the majority of the heating systems in U.S. housing[1] (Figure 3.1.1). The share of heat pumps is growing, however, since furnaces face very strong competition from heat pumps in the new construction market in warm climates. Since 1987, the role of boilers has declined considerably.

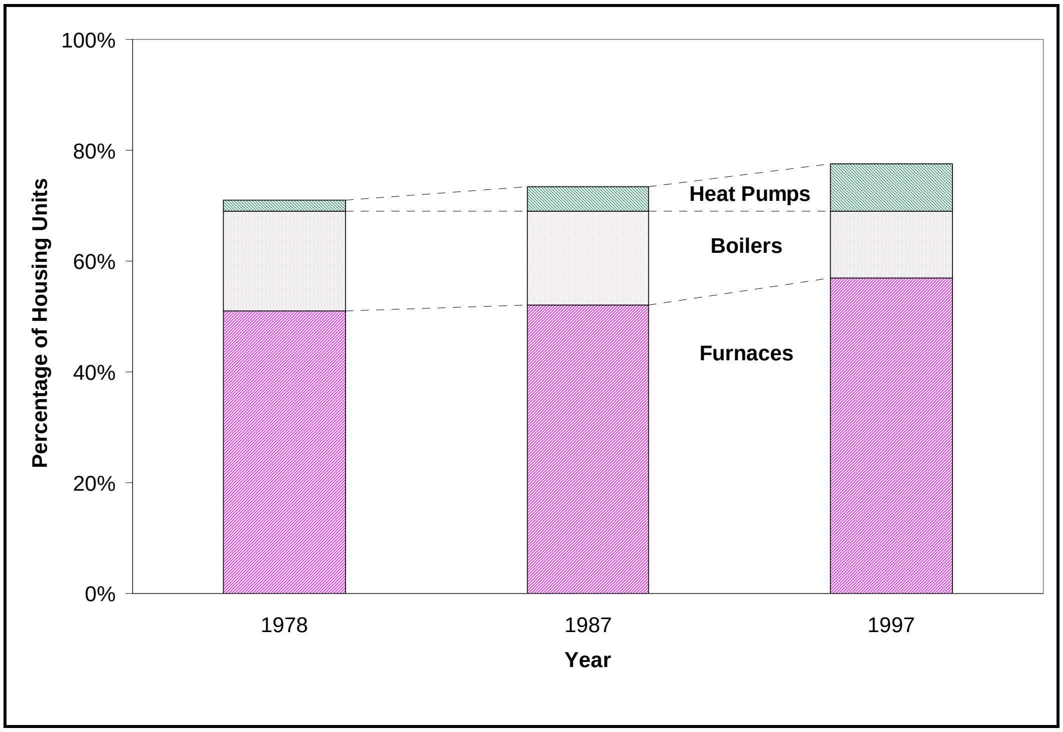

Figure 3.1.1 Saturation of Space Heating Equipment in U.S. Housing

About 20 percent of all the energy consumed in the United States is used for residential applications. With primary energy consumption of about 6 quadrillion Btu (1997 data), space heating is the largest energy end use in the residential sector, accounting for around 38 percent of total residential energy consumption. Furnaces and boilers account for over three-fourths of total residential space-heating energy consumption.

3.2 TECHNOLOGY DESCRIPTION

3.2.1 Furnace Technology

Fuel-burning furnaces provide heat by passing combustion products past a heat exchanger. Furnaces pass household air over the outside of the heat exchanger, transferring the heat from the fuel to the air. Fuel-burning furnaces exhaust the products of combustion to the atmosphere through the flue passage connected to the heat exchanger. In electric furnaces, since no products of combustion are formed, air passes directly over the electrically heated elements. Furnaces use a fan to propel the air over the heat exchanger and circulate the air through the distribution system to the house.

3.2.1.1 Types of Furnaces

There are two main types of residential furnaces: weatherized and non-weatherized furnaces. Weatherized furnaces are generally installed outdoors (often on rooftops), and non-weatherized furnaces are installed indoors.

Manufacturers test non-weatherized furnaces as an isolated combustion system (ICS), which means it is isolated from the conditioned space where it is located and the furnace draws combustion and dilution air from the outdoors. Manufacturers test weatherized furnaces under outdoor conditions.

The main difference between a weatherized furnace and a non-weatherized furnace is that the weatherized furnace is well insulated and has a weather-resistant external case. The heat loss through the jacket in a weatherized furnace is totally dissipated outside, resulting in a lower efficiency compared to an equivalent non-weatherized furnace installed indoors.

Non-weatherized gas furnaces can be either non-condensing or condensing. When the flue temperature is substantially higher than the water dew point and the latent heat (the heat from condensation of water vapor in the combustion products) is lost in the flue, the furnace is classified as non-condensing. The annual fuel utilization efficiency (AFUE) of such furnaces is generally below 83 percent AFUE. Condensing gas furnaces recover more heat from the combustion products by condensing the water vapor. There are no condensing weatherized gas and oil furnaces, because the condensate could freeze and damage the furnace.

If the furnace condenses the water (typically with the addition of a secondary corrosion-resistant heat exchanger) and drains it out, the flue temperature is much lower, and the AFUE is higher (over 90 percent). A condensing furnace requires some extra equipment, such as an additional stainless steel heat exchanger and a condensate drain device. Condensing furnaces also require a different venting system, since the buoyancy of the flue gases is not sufficient to draw the gases up a regular chimney. Plastic through-the-wall venting systems are typically used in conjunction with condensing furnaces. Condensing furnaces present a higher initial cost, but provide significant energy-efficiency gains.

Weatherized furnaces are only used as part of package units, which means that an air conditioner is in the same box. They are installed outside (often as a rooftop unit) and are properly insulated. The Department does not know of any manufacturer that presently sells a stand-alone furnace approved for outdoor installation. Manufacturers produce very few, if any, weatherized oil-fired furnaces.

Mobile home furnaces (MHFs) are a separate class of furnaces, due to three differences. They employ sealed combustion, pre-heat the combustion air, and have very tight space constraints. MHFs have historically had a lower efficiency standard and were considered as a separate product in rulemakings in the early 1990s.

3.2.1.2 Configurations

Four different designs of residential furnaces are in common use: 1) horizontal; 2) upflow; 3) multiple-direction (multipoise); and 4) downflow or counterflow. Each requires a different arrangement of its basic components.

The horizontal furnace is used in attic spaces or crawl spaces and other locations where the height of the furnace is the constraining dimension. Air enters at one end of the unit through the fan compartment, is forced horizontally over the heat exchanger, and then exits at the opposite end.

The upflow, "highboy" design is used in basements or first-floor equipment rooms, where floor space is at a premium. The fan is located below the heat exchanger. Air enters at the bottom or lower side of the unit and leaves at the top through a warm-air outlet (plenum). The upflow, "lowboy" furnace occupies more floor space and is lower in height than the highboy design, which makes it suited for basement installation. Installers place the fan alongside the heat exchanger. A return-air plenum is built above the fan compartment and a supply-air plenum is built above the heat exchanger compartment.

The downflow, or counterflow, design is used in houses that have an under-the-floor type of heat distribution system. The fan is located above the heat exchanger. The return-air plenum is connected to the top of the unit.

The multiple-direction design allows for upflow and downflow installations. Demand is growing for these products, since they allow more flexible installation. Some manufacturers noted that multiple-direction appliances are more expensive to manufacture, since they need extensive testing and more complicated controls.

Recent shipments data from the Gas Appliance Manufacturers Association (GAMA)[2] show that multiple-direction furnaces account for approximately two-thirds of total shipments. Upflow designs account for 25 percent, and downflow and horizontal designs together account for just 9 percent.

3.2.1.3 Components

Heat Exchanger. The heat exchanger is the part of the furnace where the heat is transferred from the combustion gases to the circulating air. The heat exchanger is usually made of cold-rolled, low-carbon steel with welded or crimped seams. There are two types of heat exchangers: individual-section and cylindrical.

Individual-section heat exchangers consist of a number of separate heat exchangers. Each section has individual fuel-burning devices. The sections are typically joined together at the bottom so that a common pilot can light all of the burners. The sections also are joined together at the top so that flue gases are directed to a common flue. The individual-section type of heat exchanger is used only in gas-burning equipment.

Tubular and serpentine heat exchangers are variations on the individual-section-type of heat exchanger. A tubular heat exchanger comprises several metal tubes bent in shape, while the serpentine or clam-shell heat exchanger is manufactured by folding specially-formed sheets of thin metal. Heat-exchanger designs differ from manufacturer to manufacturer, but are typically similar across all product lines for a specific manufacturer. Tubular heat exchangers require a smaller initial investment than clamshell types, but can be more costly if produced in high volume.

Cylindrical (or drum) heat exchangers have a single combustion chamber and use a single-port fuel-burning device. The cylindrical type of heat exchanger is used in both gas and oil units. All oil-fired units use cylindrical heat exchangers.

Many heat exchangers—in both gas and oil units—have primary and secondary stages. The primary one is in contact with or in direct sight of the flame and is located where the greatest heat occurs. The secondary one follows the primary stage in the path between the burner and the flue. This is used to extract as much heat as possible from the flue gases, particularly for condensing furnaces, before the products of combustion exit through the flue to the chimney.

Burner Assembly. The burner assembly functions to: 1) control and regulate the flow of gas, 2) ensure the proper mixture of gas with air, and 3) ignite the gas under safe conditions. To accomplish these actions, a gas burner assembly consists of four major parts or sections: a gas valve, an ignition device, a manifold and orifice, and gas burners and adjustments.

The gas-valve section consists of a number of parts—a hand shutoff valve, a pressure-reducing valve, safety shutoff equipment, and an operator-controlled automatic gas valve—each performing a different function. On older units, these operations were entirely separate. In modern units (and some current models of MFH and gas boilers), these parts are all contained in a combination gas valve (CGV).

On older furnaces, ignition was accomplished through the use of a standing pilot. The vast majority of today's furnaces use hot-surface ignition, which is perceived to be more reliable and yields higher efficiency (no gas is consumed during standby mode). Hot-surface igniters are typically composed of a silicon carbide element that performs both ignition and flame detection. The igniter is an electrically heated resistance element that thermally ignites the gas. The flame detector circuit uses flame rectification for monitoring the gas flame. The ignitor serves two functions. Upon a call for heat, the element is powered by the 120-Volt alternating current (AC) line and allowed to heat for a number of seconds (typically 37). Then the main valve is powered, permitting gas to flow to the burner for the trial-for-ignition period, which is typically seven seconds long. At the end of this period, the igniter is switched from its heating function to that of a flame probe, which checks for the presence of flame. If a flame is present, the system will monitor it and hold the main valve open. If a flame is not established within the trial-for-ignition period, the system will lock out, closing the main valve and shutting off power to the igniter. If a loss of flame occurs during the heating cycle, the system will re-cycle through the ignition sequence. Proper location of the silicon carbide igniter is important for optimum system performance, and the igniter needs to be periodically re-aligned.

The manifold connects the supply of gas from the gas valve to the burners, and delivers gas equally to all of the burners. The orifices permit a fast stream of raw gas to enter the burner, and meter the gas flow. They are typically small brass fittings with carefully sized holes drilled in them. Small changes in furnace capacity rating can be made by changing orifices.

Gas-burning devices require air (oxygen) to be supplied in the right amount. Primary air (air that is pre-mixed with the gas prior to combustion) is nearly one-half of the total air required for combustion. Secondary air, which is supplied to the flame at the time of combustion, should be more than about 50 percent of the total supply, to prevent the formation of carbon monoxide. To produce a good flame, it is essential to maintain the proper ratio between primary and secondary air. In gas furnaces, the fuel enters the burner through a venturi tube that creates a high gas velocity. In turn, the high velocity creates a sucking action that causes the primary air to enter the tube and mix with the raw gas. In gas furnaces, the burners are typically single-port (or inshot), meaning that one long flame is directed into the heat exchanger section after ignition.

In an oil-fired furnace, the oil burner is typically a high-pressure, atomizing burner. A high-pressure gun burner forces oil at 100 pounds-per-square-inch gauge (psig) pressure through the nozzle, breaking the oil into fine, mist-like droplets. Some models require operating oil-pump pressures in the 140–200 psig range. The atomized oil spray creates a low-pressure area into which the combustion air flows. Combustion air is supplied through vanes, creating turbulence and completing the mixing action. The main components of a high-pressure burner are the power assembly (fuel pumps, motor, fan, and air shutters) and the nozzle assembly. All high-pressure burners have electric ignition. A step-up transformer supplies the power to two electrodes, which causes a spark to jump. The force of the air in the blast tube causes the spark to arc into the oil-air mixture, igniting it. Ceramic insulators surround the electrodes where they are close to metal parts and serve to position the electrodes. The oil is typically stored in a separate tank and is piped to the furnace.

Air Blower. The circulating air blower of a residential central furnace is a centrifugal fan-impeller with a shaft-mounted motor. The assembly with the fan shroud is mounted in an enclosure at the base of an upflow furnace or the return-air end of a horizontal unit. This plenum box may have an integral air-filter rack. The output of the fan goes directly to the air side of the furnace heat exchanger, and then through the indoor (evaporator) coil of the air conditioner if one is present. The air blower and the indoor coil are housed in a factory or field-fabricated plenum called an air handler. In general, the air handler is too small for optimum air flow, and lacks air movement guides. The air is distributed throughout the house using ducts. Residential duct-work typically does not include turning vanes or other air-flow aids, and consequently has relatively high friction losses and static pressure.

Air blowers in residential furnaces generally use multi-speed induction motors, typically permanent split capacitor (PSC) designs. Premium furnaces may offer electronically commutated (brushless permanent magnet) motors, which have a higher efficiency and other features, such as modulating capacity controlled by the thermostat.

Depending on the quantity of air moved and the resistance of the system, a motor of the proper size is selected for the furnace. Because the resistance of the system cannot be fully determined beforehand, it may be necessary to make some adjustment to the motor speed at the time of installation. Generally, the higher the speed of the fan, the greater the cubic foot per minute (cfm) output, thereby requiring more power and often a higher horsepower motor. Because of the higher air-flow requirements of air-conditioners, the requirements of the air conditioning system frequently determine the size of the motor.

The electricity consumed by the blower is a function of the air-flow rate and the efficiency of the blower assembly. The most important determining factors for the airflow are the capacity of the air conditioner associated with the furnace (if any) and the capacity of the furnace itself. The capacity of the air conditioner associated with the furnace strongly influences the air-blower size selection, because of the high air-flow requirements—except in very cold climate situations, where the air conditioner may require a lower air-flow rate than the furnace. Therefore, warmer climates require a more powerful air blower to satisfy the requirements of larger air conditioners (leading to higher electricity consumption).

Draft Inducer Fan. The draft inducer fan typically uses a motor in the 75–90 watt size range. Variable-speed and two-speed draft inducer motors are also available.

Controls. Automatic controls operate the heating system in response to variable conditions, by turning the various components on and off. The automatic controls are capable of switching the house conditioning system from heating to cooling mode. These devices operate in response to a controller, usually a thermostat, that senses the room temperature, and activates the equipment to maintain the desired conditions.

3.2.1.4 Mobile Home Furnaces

Mobile home furnaces differ from regular furnaces in several ways. First, they use sealed combustion (i.e., all combustion air is from the outside). Second, most MHFs pre-heat the air (typically to 50–60°F), using a concentric vent where the combustion air is drawn in through the outer ring, while exhaust gases are vented through the inside core of the vent pipe. The air is pre-heated because cold air does not mix very well with the fuel, while pre-heated air blends well and allows for quieter ignition and combustion. Finally, MHFs have to comply with strict space restrictions (typically 20"-by-24" closets).

Typically MHFs use drum-type heat exchangers, and most have a downflow configuration. The air-flow rate is dictated by the cooling load, and the furnace typically has a multi-speed blower, which is adjusted at the time of installation to provide a higher or lower air-flow rate.

Mobile home furnaces are designed to handle a limited amount of condensate. Typically, the condensate runs down the drum and evaporates. The vent system is aluminized steel, as is the heat exchanger.

Most MHFs are now designed with a cabinet for the air-conditioning coil, since about estimated three-quarters of new mobile homes have air conditioning.

In general, the features on MHFs are low cost, as the market is composed of low-income customers, and profit margins are low.

3.2.1.5 Electric Furnaces

Residential electric furnaces have a resistance-type heating element that heats the circulation air, either directly or through a metal sheath enclosing the resistance element. The definition of electric furnaces is complicated by the fact that blower boxes built to be combined with a heat pump are often equipped with electric heating elements. These units are technically considered electric furnaces, but they do not meet the Energy Policy and Conservation Act (EPCA) definition for electric furnaces, because the equipment is not designed to be the principal heating source for the living space of a residence.

The only heat loss associated with an electric furnace is in the cabinet—amounting to about 2 percent of input. Both the steady-state efficiency and annual efficiency of an electric furnace are greater than 98 percent, and if the furnace is located within the heated space, the heating-season efficiency is 100 percent.

3.2.1.6 Input Rate

Table 3.2.1 shows the median input rate (hereafter referred to as "input capacity") of the models in each furnace product class. Figures 3.2.1 through 3.2.3 show the distribution of models at different capacity ratings.

Table 3.2.1 Median Capacity of Furnace Models in the GAMA Directory

Product Class	**kBtu/hr**
Non-weatherized gas furnaces	90
Weatherized gas furnaces	80
Non-weatherized oil-fired furnaces	120
Mobile home gas furnaces	77

Source : GAMA Directory, 2001.

None of the manufacturers interviewed has observed a decisive trend in average capacity. While improvements in building envelope design have tended to push manufacturers to design smaller systems, the increasing size of new homes calls for larger systems.

Although mobile homes are getting larger and more similar to regular homes, MHFs tend to have a lower capacity than do regular furnaces. Their typical capacity ranges from 60,000 to 100,000 Btu/hr input.

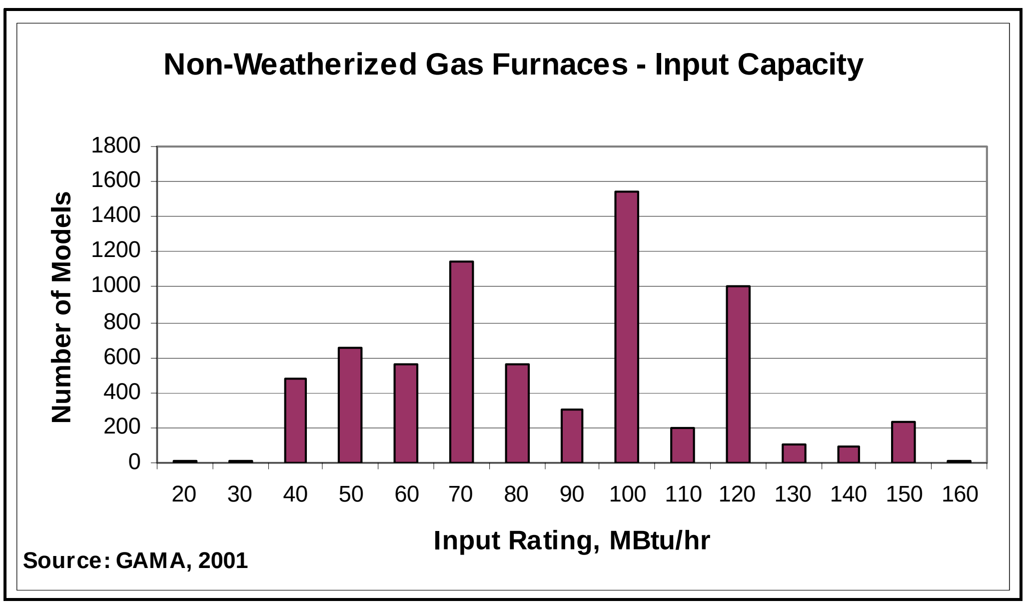

Figure 3.2.1 Distribution of Non-Weatherized, Gas Furnace Models by Input Capacity

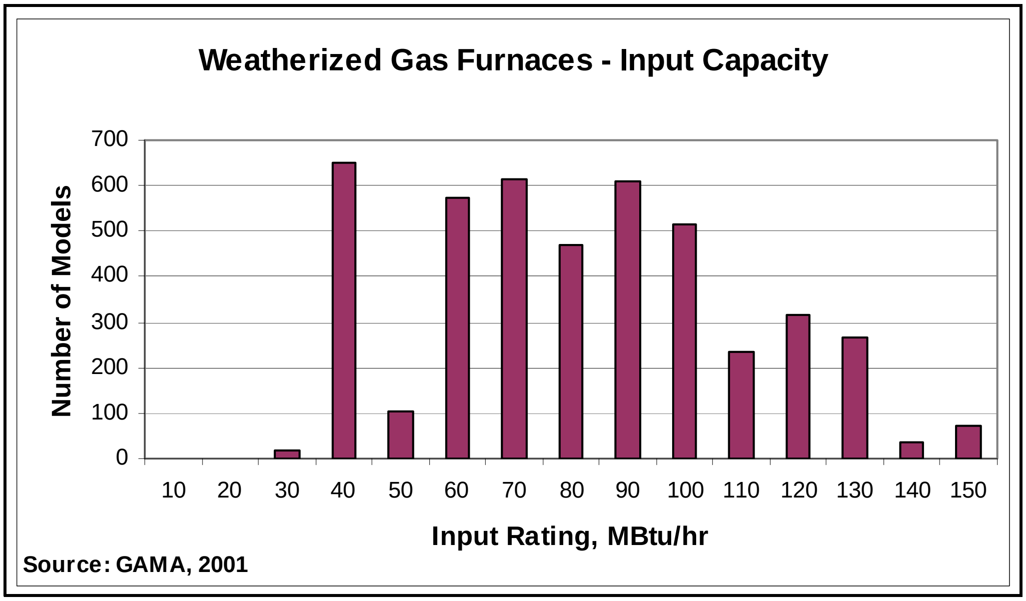

Figure 3.2.2 Distribution of Weatherized, Gas Furnace Models by Input Capacity

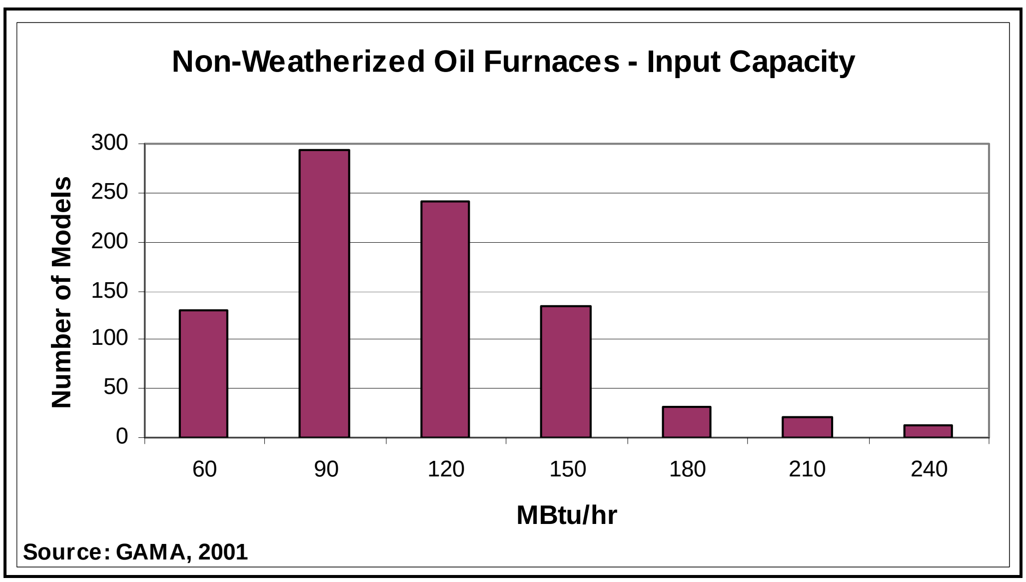

Figure 3.2.3 Distribution of Non-Weatherized, Oil-Fired Furnace Models by Input Capacity

3.2.1.7 Electricity Consumption

The circulating-air blower typically accounts for 70–90 percent of furnace total electricity consumption. The draft inducer accounts for most of the remainder. The GAMA directory and manufacturers' literature both list the annual auxiliary electrical energy (E_{AE}) in kilowatt hours (kWh). Table 3.2.2 provides the median values in each product class. The values are higher in oil-fired furnaces, due to the presence of the oil burner. Figure 3.2.4 shows the distribution of values of E_{AE} for non-weatherized gas furnaces.

Table 3.2.2 Median Annual Auxiliary Electricity Use of Furnace Models

Product Class	kWh
Non-weatherized gas furnaces	832
Weatherized gas furnaces	764
Non-weatherized oil-fired furnaces	958
Mobile home gas furnaces	719

Source: GAMA, 2001

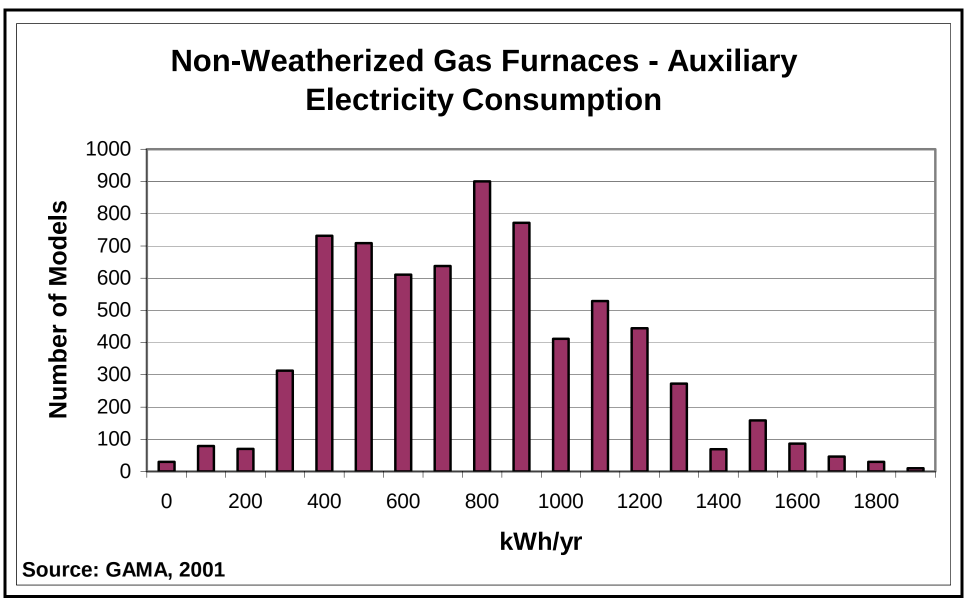

Figure 3.2.4 Distribution of Electricity Consumption Values for Non-Weatherized, Gas Furnace Models

3.2.2 Boiler Technology

Boilers are heating devices that transfer heat from the combustion gases to water, which then heats up the required space through a hydronic (hot-water) or steam distribution system. The technology used for steam boilers is the same as for hot-water boilers, except that circulating pumps are not used in steam boilers. Boiler capacities range greatly, but they tend to be higher than furnace capacities.

3.2.2.1 Types of Boilers

Boilers on the market are distinguished by the type of material: cast-iron sectional, steel fire-tube, copper water-tube, and aluminum. Cast-iron boilers are the most popular and are typically gas fired. Steel boilers are also fairly popular, are perceived to be less expensive, and are always oil fired. Copper boilers are less popular and are typically used for particular short-response-time small systems. Aluminum boilers are relatively uncommon.

Hot-water boilers are found in all of the above material types. Steam boilers are either cast-iron sectional or steel fire-tube type.

Cast-iron sectional boiler. The cast-iron sectional boiler is the most common design used in residential and light-commercial buildings. In this design, water is heated in cast-iron chambers called sections. The sections are compression-fit together to form a boiler block. Hot combustion gases form in the combustion chamber near the bottom of the boiler and rise through cavities between the sections, transferring heat to the water within. The greater the number of sections, the greater the rate of heat output from the boiler.

Most cast-iron sectional boilers for residential use are sold as packaged boilers. This means that components such as the pump, burner, and controls are selected and installed in the boiler by the manufacturer. The components selected by the manufacturer are sized for a typical residential system. In some cases, one or more of these components may not be the best choice for a specific house plan. For example, the small pump supplied as part of a packaged boiler may not be able to produce the flow rate and pressure differential required by an extensive radiant floor-heating system. For this reason, some manufacturers also sell a "bare-bones" version of the boiler without such components.

Cast-iron sectional boilers are limited to use in closed-loop hydronic systems. Properly designed closed-loop systems rid themselves of excess air in the system water after a few days of operation. At this point, the potential for corrosion damage to the cast-iron sections from the water is very small. Improperly designed or installed systems that result in a continued presence of dissolved air in the system's water will rapidly corrode cast iron. Persistent water leaks, chronic opening of pressure-relief valves, and misplaced air vents are all possible sources of dissolved air. When properly used, cast-iron boilers can last for decades.

The amount of metal in cast-iron boilers makes them relatively heavy. A residential-size boiler can weigh from 350 to 500 pounds. These boilers also typically contain 10 to 15 gallons of water. The combination of metal- and water-weight enables them to absorb a significant amount of heat into their own material. This high thermal mass is undesirable in situations where the boiler is significantly oversized, and thus experiences extended periods of off-time between firing cycles. During this time, residual heat remaining in the boiler's metal and water following burner shutdown can be carried up to the flue by air currents passing through the combustion chamber. Most gas-fired boilers have flue dampers to reduce this heat loss. Part of the residual heat is also transferred through the boiler's housing (jacket) to the air surrounding the boiler.

A wet-base boiler is a very common configuration for oil-fired boilers. It has the advantage of exposing more of the section's surface area to the combustion chamber, which is completely surrounded by the water-filled heat exchanger.

A dry-base boiler is commonly used for atmospheric gas-fired boilers. Combustion occurs on the surface of burner tubes suspended below the water-filled sections. Hot exhaust gases are drawn upward between boiler sections, or through fire tubes, and enter a flue gas collector at the top of the boiler. Room air is always directly available at the burner tubes.

Steel fire-tube boiler. In a steel fire-tube boiler, water surrounds a group of steel tubes through which the hot combustion gases pass. Spiral baffles known as turbulators are inserted into the fire tubes to increase heat transfer by inducing turbulence and slowing the passage of the exhaust gases. The fire tubes are welded to steel bulkheads at each end to form the overall heat-exchanger assembly.

Most steel boilers are built around horizontal fire-tubes. Some boilers route the flue gases through multiple tubes before they reach the flue-pipe connection. This allows additional heat to be extracted from the flue gases. In general, multiple-pass horizontal boilers will have slightly higher efficiencies compared to vertical fire-tube boilers. This is due to the greater contact area between the boiler water and fire tubes. Like cast iron, steel is subject to corrosion from dissolved air in the system water. Because of this, steel fire-tube boilers are also limited to closed-loop system applications.

Although steel fire-tube boilers generally have less metal weight than comparative models of sectional cast-iron, their water content is often greater. Residential-size boilers often contain 15 to 30 gallons of water. This again results in a boiler with a relatively high thermal mass and, thus, potential for higher off-cycle heat losses.

Copper water-tube boilers. In copper water-tube boilers, the tubes are directly exposed to the combustion gases. Design variations include both vertical and horizontal-tube arrangements. The tubes are usually manufactured with fins that greatly increase the heat transfer area exposed to the flue gases. The high thermal conductivity of copper, relative to cast iron or steel, means that significantly less surface area is needed to achieve the same rate of heat transfer. This makes for smaller and significantly lighter boilers. These boilers use natural gas as their fuel.

Copper water-tube boilers require constant water circulation while being fired to prevent damage from thermal stress. This requirement must be incorporated into the design of system piping and control.

Due to their corrosion resistance, some copper-tube boilers are suitable for direct heating of domestic water and swimming pools. The light construction and low water content result in a low thermal-mass boiler with fast warm-up.

3.2.2.2 Boiler Input Rate

Hot-water boilers in the market have a very wide range of capacities (Figure 3.2.5). Oil-fired boilers tend to be larger than gas boilers.

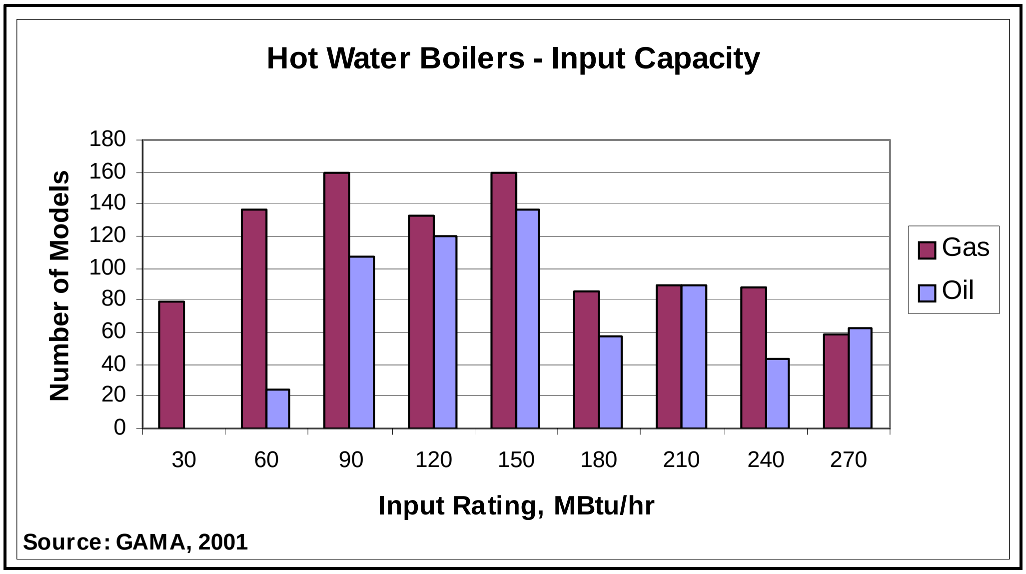

Figure 3.2.5 Number of Hot-Water Oil and Gas Boiler Models by Input Capacity

3.2.2.3 Boiler Electricity Consumption

Electricity consumption in boilers is much lower than in furnaces, since the circulating-air blower is replaced by a pump, which requires much less energy. Oil-fired boilers tend to consume much more electricity, since they include an atomizing device, a combustion-air blower, and spark ignitor within their assembly. The median values are 130 kWh/yr for gas hot-water boilers and 341 kWh/yr for oil hot-water boilers. Electricity is not used in most gas-fired steam boiler models. Figure 3.2.6 shows the distribution of electricity consumption among hot-water boiler models.

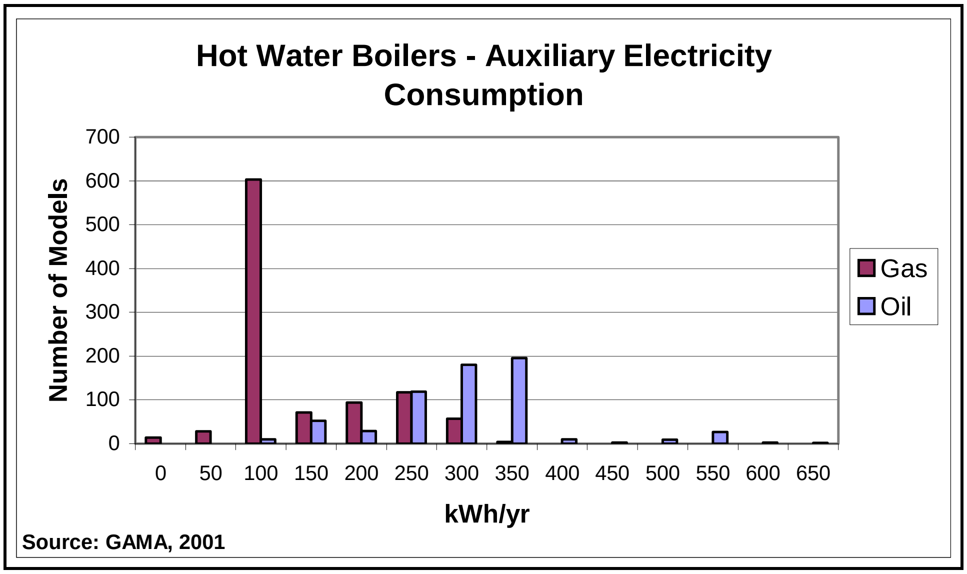

Figure 3.2.6 Distribution of Electricity Consumption Values for Hot-Water Boiler Models

3.2.3 Combination Space- and Water-Heating Appliances

Combination space- and water-heating appliances fall into two major classes: (1) boiler/tankless-coil combination units, and (2) water-heater/fancoil combination units. A great majority of boiler/tankless-coil combination units are fired with oil, whereas most water-heater/fancoil combination units are fired with natural gas.

Boiler/Tankless-Coil Combination Units. In these units, the primary design function is space heating. Water heating is provided by one of the following different configurations:

(1) Tankless heater directly in boiler: There is no water-heating tank. The heat exchanger that heats domestic hot water is in the boiler.

(2) Tankless heater in external tank: Boiler hot water is stored in an external tank in which the water-heating heat exchanger for the domestic hot water is submerged.

(3) Integrated heater: Domestic hot water is in the tank and the heat exchanger circulating boiler-water is submerged in the tank.

Space heating can be provided by a standard hydronic configuration, or the boiler can be connected to an air-handling system. The key components of these combination units include a boiler, a tank (in some configurations), a water-to-water heat exchanger, and a water pump.

Typical input rates range from 150 to 300 kBtu/hr. The tank size (if there is one) is 30 to 80 gallons.

Water-Heater/Fancoil Combination Units. In these units, the primary design function is domestic water heating. Domestic hot water is circulated through a heating coil of an air-handling system for space heating. Usually the water heater is a tank-type gas-fired water heater, but instantaneous gas-fired water heaters can be used as well.

The key components of these combination units are a water heater, a circulating-air blower, a hydronic water-to-air heat exchanger, a water pump, and an air-conditioning evaporator coil (if space cooling is provided).

A space-heating zone thermostat activates the water pump and air blower when heating is needed in the building. The hot-water thermostat is set to about 140° F. Tank water is mixed with cold water to reduce temperatures for domestic hot water to about 120°F, to avoid scalding danger. Tankwater temperature decreases whenever there is a hot-water draw, when space heating is being provided, or when standby losses occur. The water-heater thermostat activates the burner when the water temperature drops below a set thermostat point. In some installations, a temperature sensor is used to signal a water draw and the air handler is shut down, giving priority to the domestic hot water needs of the occupants.

Typical input rates for storage water heaters are in the 40 to 75 kBtu/hr range. The tank size is in the range of 30 to 80 gallons. Air handlers are sized to meet the building's heating loads (and cooling loads, if used with an air conditioner). Water-heater/fan-coil combination units are most suitable for use in regions with lower heating loads.

3.3 EFFICIENCY CHARACTERISTICS

3.3.1 Efficiency Standards

The National Appliance Energy Conservation Act (NAECA) legislation of 1987 established efficiency standards for residential furnaces and boilers (Table 3.3.1). The effective date for these minimum-efficiency standards was January 1, 1992, with the exception of the standard for mobile home furnaces, for which the effective date was September 1, 1990.

Table 3.3.1 Current Federal Residential Furnace and Boiler Minimum Efficiency Standards

Product Class	Minimum AFUE
Gas furnaces	78%
Oil-fired furnaces	78%
Mobile home furnaces	75%
Gas steam boilers	75%
All other boilers	80%

At the present time, there are no federally prescribed testing and rating standards or minimum-efficiency levels for combined appliances. However, federal statutes do require that the energy-converting component of a combined appliance (i.e., the boiler or the water heater) be tested and rated to provide efficiency ratings for the primary function. The Department is in the process of adopting a test procedure for combined appliances. Although the efficiency of the secondary function in combination units is not federally regulated, many jurisdictions in the United States have building or energy codes that require reporting of the efficiency of the secondary function to show compliance.

3.3.2 Furnace Efficiency

Most of the non-weatherized gas furnaces on the market have an efficiency of 80 percent AFUE (Figure 3.3.1). This level is generally considered safe by manufacturers, because vent and heat-exchanger corrosion resulting from excessive condensation is not common with units at 80 percent AFUE or below. A few 78 percent models are still on the market to address situations in which venting condensation might become a particular concern (e.g., exterior masonry chimneys). Condensing models range mostly between 90 percent and 94 percent AFUE. Roughly one-quarter of current sales are condensing models.

There are no gas furnaces in the 83–89 percent AFUE range. In this range, condensate problems begin to occur, but the temperature of the flue is still too high to allow the use of polyvinylchloride (PVC) for the venting system. Proper venting of such a furnace requires a special venting system.

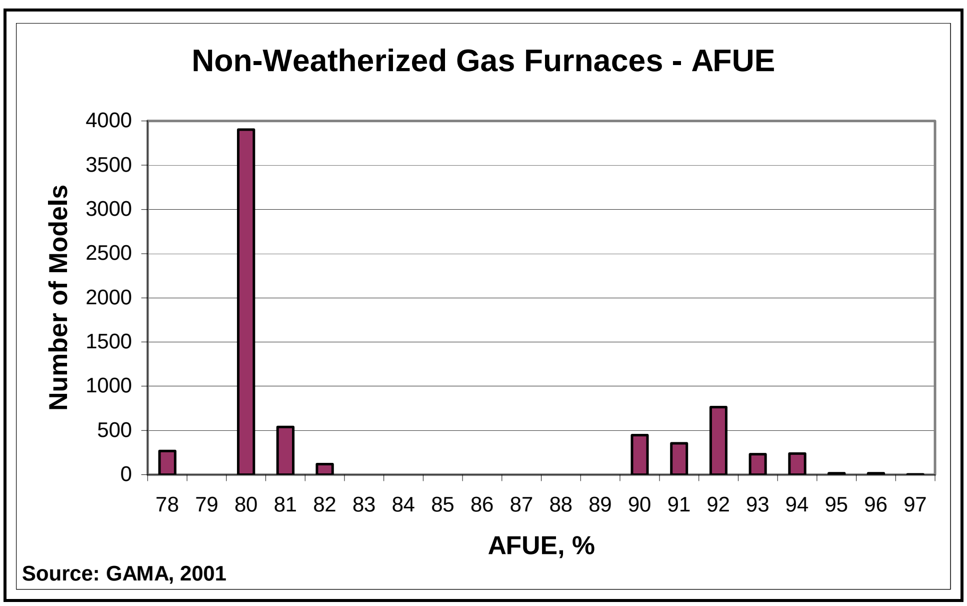

Figure 3.3.1 Distribution of Non-Weatherized Gas Furnace Models by Efficiency

The efficiency distribution of weatherized gas furnace models is similar to that of non-condensing non-weatherized gas furnaces (Figure 3.3.2).

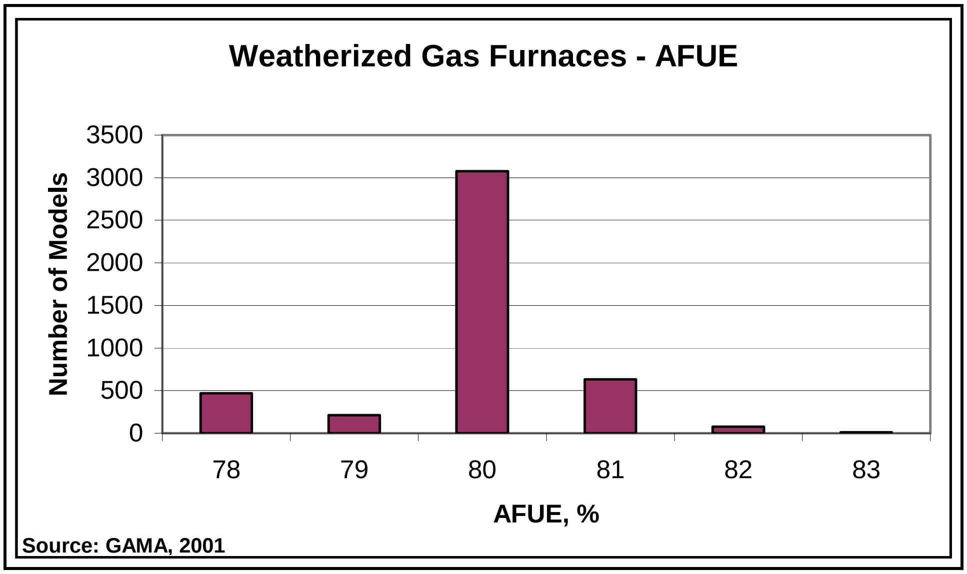

Figure 3.3.2 Distribution of Weatherized Gas Furnace Models by Efficiency

Compared to gas furnaces, there are more oil-fired furnace models with an AFUE in the 82–86 percent range (Figure 3.3.3). Because of the lower hydrogen content of fuel oil compared to natural gas or propane, oil-fired furnaces pose no condensate problems at these AFUE levels. No condensing oil-fired furnaces currently exist.

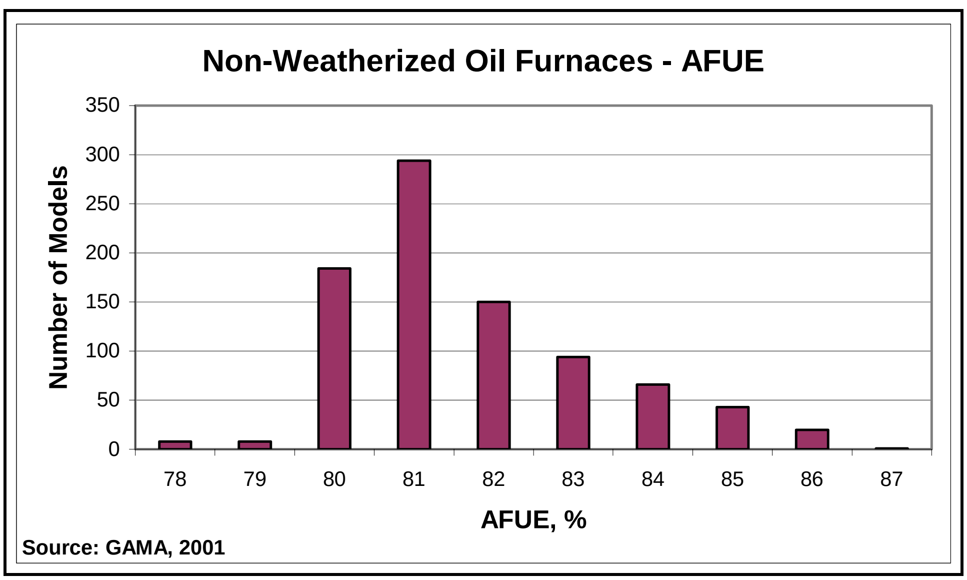

Figure 3.3.3 Distribution of Oil-Fired Furnace Models by Efficiency

The efficiency of gas MHFs on the market is generally either 75 percent or 80 percent (Figure 3.3.4). There are some condensing models.

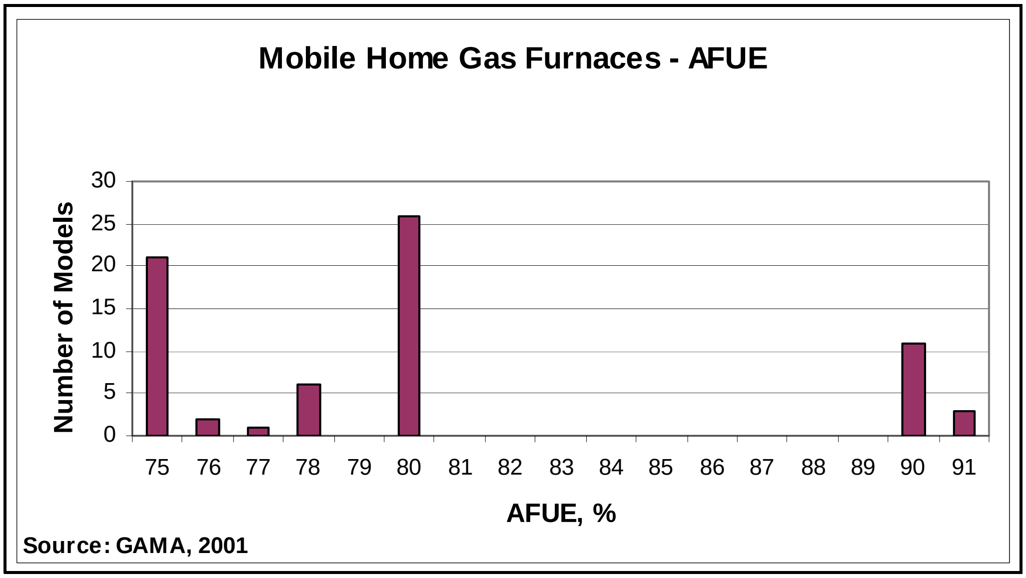

Figure 3.3.4 Distribution of Mobile Home Gas Furnace Models by Efficiency

3.3.3 Boiler Efficiency

Most gas hot-water boilers have an AFUE in the 80–84 percent range, but oil hot-water boilers are typically more efficient (Figure 3.3.5). Gas steam-boiler models have an AFUE in the 78–82 percent range, while oil models have AFUEs that are considerably higher (Figure 3.3.6).

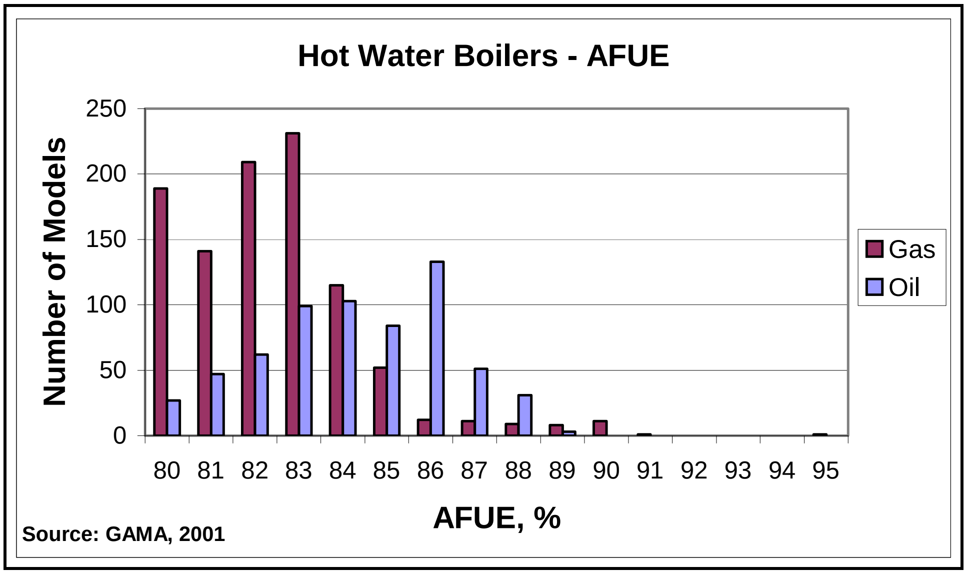

Figure 3.3.5 Distribution of Efficiency Values for Hot-Water Boiler Models

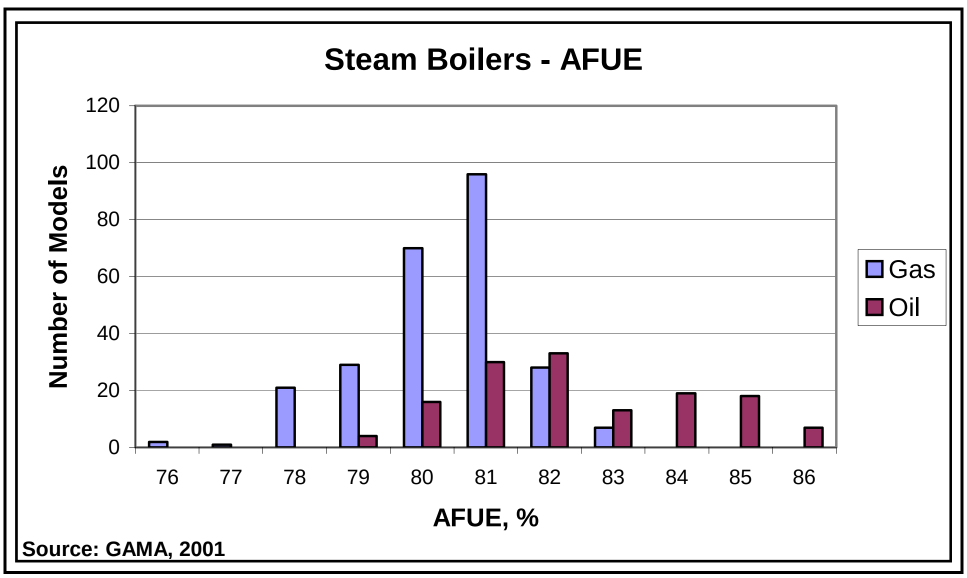

Figure 3.3.6 Distribution of Efficiency Values for Steam Boiler Models

3.3.4 Combination Space- and Water-Heating Appliances

For water-heater/fan-coil combination units listed in the GAMA directory,[3] the effective efficiency of space-heating performance ranges between 71 percent and 91 percent. Most models listed are in the 78–82 percent range. A few models use a condensing water heater and achieve an AFUE of around 90 percent.

The efficiency range of boiler/tankless-coil combination units for space heating is similar to hot-water boilers, shown above in Figure 3.3.5.

3.4 MARKET FOR FURNACES AND BOILERS

3.4.1 Shipments Trends

GAMA provided extensive historical shipment data to DOE.[2] Where the data from GAMA were insufficient, DOE estimated historical shipments for each of the product classes, using other data sources.

The GAMA data give shipments for gas furnaces, including mobile home furnaces, as a group (Figure 3.4.1).

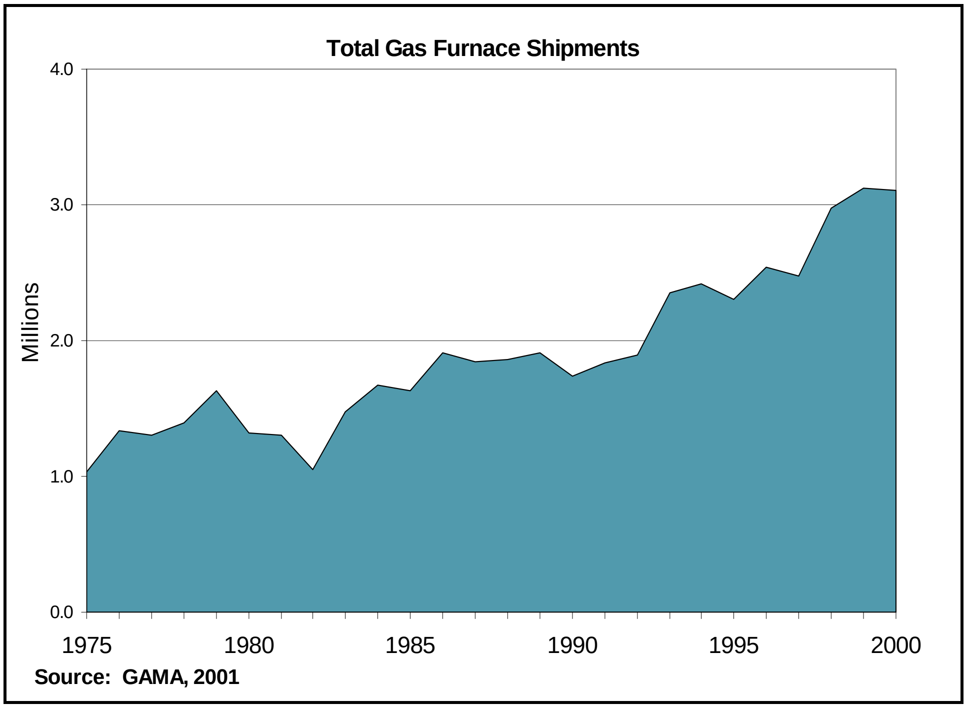

Figure 3.4.1 Total Gas Furnace Shipments, 1975-2000

The Department found no separate data on shipments for weatherized furnaces. The Department estimated shipments of weatherized gas furnaces based on estimated 1990–1997 shipments of packaged air-conditioning equipment, since the latter are typically coupled with a weatherized gas furnace. These data suggest that weatherized gas furnaces account for 12 percent of total gas-furnace shipments (not including mobile home gas furnaces). The Department classified the remaining gas furnaces as non-weatherized gas furnaces.

The Department estimated mobile home gas furnace shipments from total mobile home placements (from the Census Bureau),[4] and from American Housing Survey[5] data that give the share of gas furnaces in existing mobile homes of various vintages.

The GAMA data give shipments for oil-fired furnaces. Since there are very few weatherized oil-fired furnace models, DOE assumed that all of the shipments are non-weatherized.

The GAMA data provide total shipments by fuel type for boilers. For each fuel, DOE estimated the split between hot-water and steam types, based on estimates made by GAMA in the early 1990s.

Table 3.4.1 shows the estimated annual shipments in 2000 and the number of models in each of the product classes. For some combination units, DOE reports a range of possible shipment figures. Non-weatherized gas furnaces are by far the largest category.

Table 3.4.1 Market Statistics for Furnaces and Boilers by Product Class

Product Class	**Estimated Shipments in 2000**	**Number of Models (2001)**
Non-weatherized gas furnaces	2,645,000	6907
Weatherized gas furnaces	325,000	4476
Non-weatherized oil-fired furnaces	120,000	868
Weatherized oil-fired furnaces	few	13
Mobile home gas furnaces	130,000	70
Mobile home oil-fired furnaces	few	16
Hot-water gas boilers	190,000	990
Hot-water oil-fired boilers	100,000	640
Steam gas boilers	36,000	254
Steam oil-fired boilers	13,000	140
Electric resistance furnaces*	420,000	uncertain
Boiler/tankless-coil combination units	50,000–75,000	not applicable
Water-heater/fancoil combination units	170,000–200,000	~40

Source for number of models: *GAMA Directory*, 2002

* Includes mobile home electric furnaces. Estimates of annual shipments of electric resistance furnaces are somewhat uncertain. Data from GAMA end in 1997. Confidential data from Air-Conditioning and Refrigeration Institute (ARI) show a higher number over the past decade. Part of the discrepancy is probably due to the lack of a clear definition of what constitutes an electric furnace.

Estimated annual shipments of MHFs rose significantly in the 1990s (Figure 3.4.2). The share of electric furnaces has grown significantly, while the gas share has decreased. The share of oil-fired furnaces is only around 2 percent, according to manufacturers interviewed. The reason for the sharp decline in gas-fired MHFs lies in the demographics of the market. Mobile homes are often placed in rural areas where natural gas is not readily available, so electric furnaces represent an attractive alternative. Furthermore, mobile home owners are typically lower-income families and first costs are an important decision factor. Oil-fired furnaces are disappearing from the MHF market.

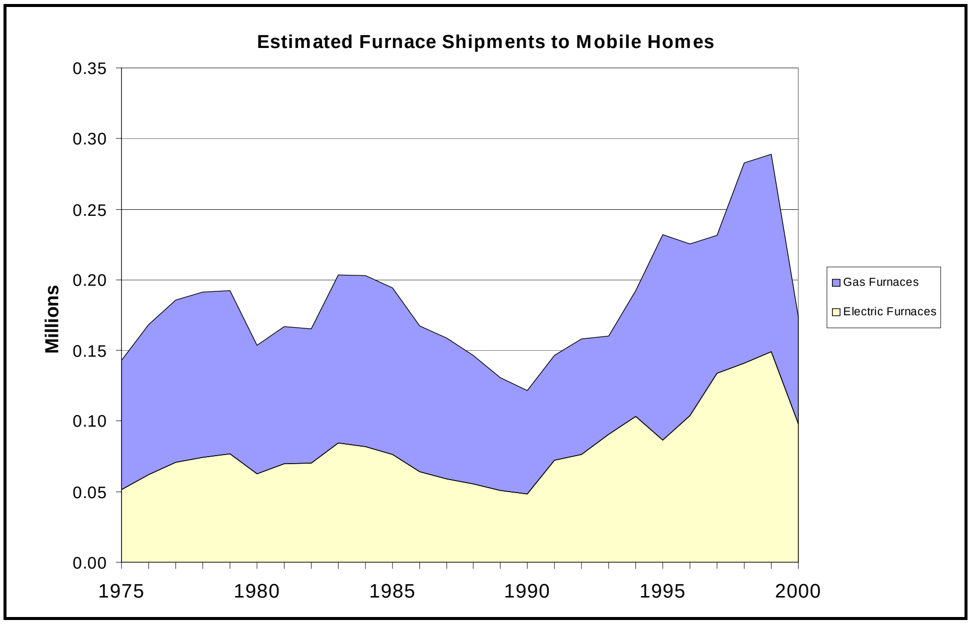

Figure 3.4.2 Estimated Furnace Shipment to Mobile Homes

The trend of annual shipments for residential oil-fired furnaces has been generally steady since the mid-1980s (Figure 3.4.3). The oil-fired furnace market is regional. Most of the sales are in the Northeast and Mid-Atlantic regions.

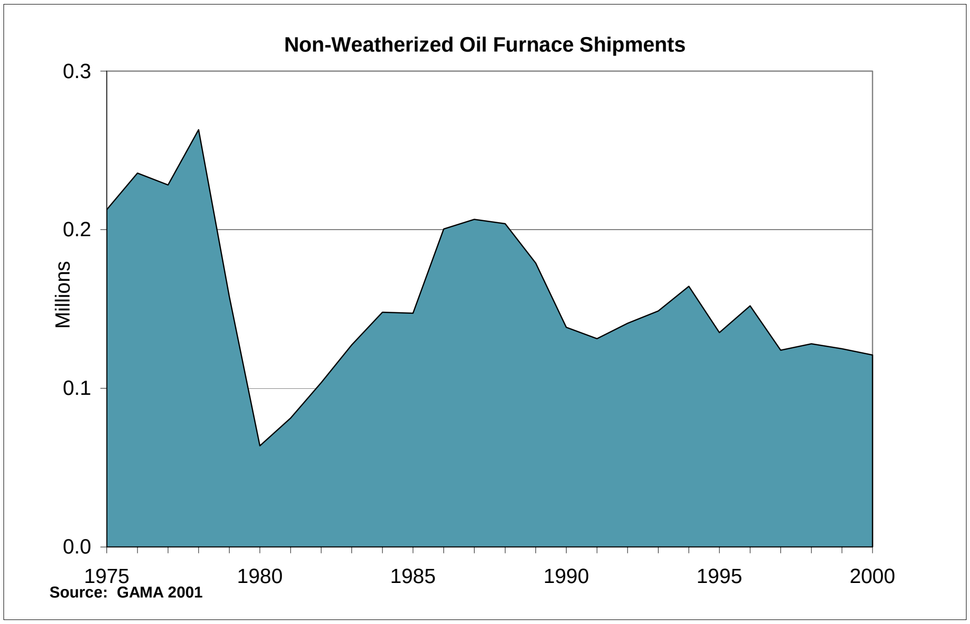

Figure 3.4.3 Shipments of Oil-Fired Furnaces, 1975-2000

The trend of annual shipments for residential gas and oil-fired boilers has been generally flat since the mid-1980s (Figure 3.4.4). Hot-water boilers make up about 84 percent of total gas-boiler shipments and 90 percent of total oil-fired boiler shipments. The boiler market is regional. Most of the sales are in the Northeast and Mid-Atlantic regions, with a few pockets in the West, Midwest, and the South. The steam boiler market is mostly concentrated in some urban pockets in the Mid-Atlantic and Northeast regions.

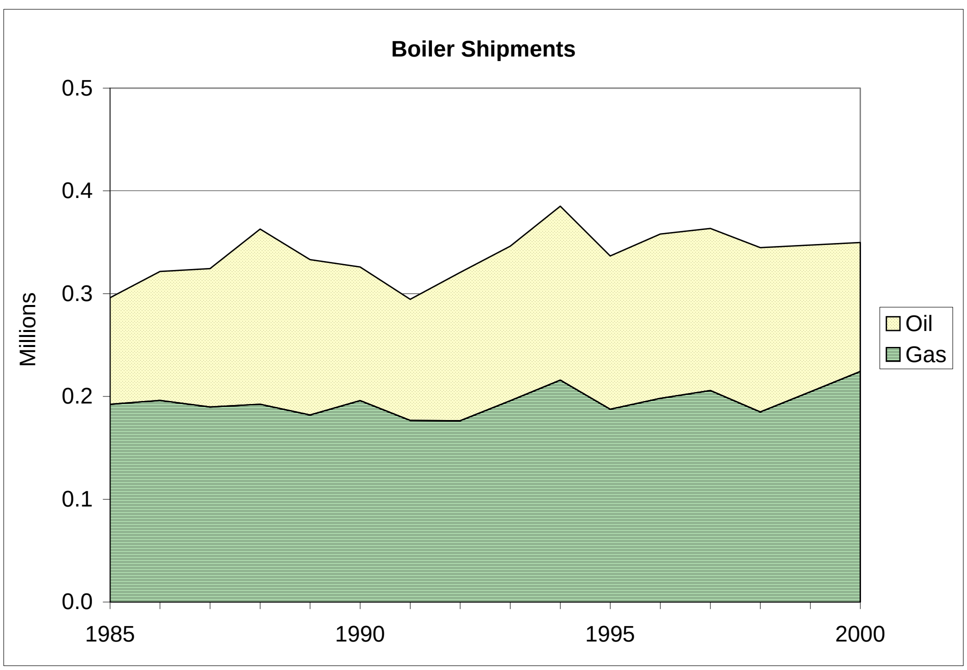

Figure 3.4.4 Shipments of Residential Boilers

Combination units are often site-built; the shipment figures for the individual components—water heaters and boilers—do not contain information regarding the final installation configuration. The Department estimates annual shipments of tankless coils to be around 150,000 units. About 100,000 of these are delivered to boiler manufacturers and 50,000 are delivered to the replacement market. Sources estimate that more than 95 percent of the tankless coils end up being used in hot-water boilers fueled by oil. The reasons for this are: (1) if gas is connected to the facility, it is cheaper to install a separate gas water-heater; and (2) water heaters fueled by oil are expensive and it is cheaper to use the boiler for water heating.

An industry source estimated annual shipments of 50,000 to 75,000 units of integrated (indirect) water heaters. Most of these units are connected to oil-fired hot-water boilers for the same reasons that tankless-coil units are connected to these units. If the above estimates are correct, a substantial share of the oil-fired hot-water boilers produced also provide domestic hot-water service.

A Gas Research Institute (GRI)-sponsored study[6] estimated the number of installations of water-heater/fan-coil combination units in 1998 in the South Census Region to be about 170,000. Most of the installations were in new construction and took the place of electric furnaces or gas furnaces. The survey indicated that one major reason for the low penetration of combination units is the lack of familiarity with combination systems among space-conditioning professionals and consumers. The estimate above does not include installations in the West, which also has regions where water-heater/fan-coil combination systems are suitable.

3.4.2 Manufacturers

Five manufacturers account for about 85–90 percent of sales of non-weatherized gas furnaces (Table 3.4.2). Several consolidations took place in recent years. Among the most important ones were International Comfort Products (ICP) with Carrier, Goodman with Amana, and Ducane with Lennox.

The main manufacturers of oil-fired furnaces are Lennox, Carrier, Williamson-Thermoflo, and Nordyne Inc.

Every manufacturer that makes residential air conditioners and heat pumps makes electric furnaces. The reason for this is that the indoor fan-coil unit for a heat pump is essentially the same product as an electric furnace. If the fan-coil unit is installed with an air conditioner instead of a heat pump, it becomes an electric furnace. It also can be installed without a coil to become a heating-only electric furnace. Rheem, ICP, Trane, and Lennox account for approximately 90 percent of the market for electric furnaces.

Table 3.4.2 Manufacturer Market Shares for Non-Weatherized Gas Furnaces (%)

Manufacturer	1995	1998	2000
Carrier/ITC	21	23	31
International Comfort Products	10	10	
Goodman	14	17	17
Amana	3		
Lennox	11	12	15
Ducane	2		
American Standard (Trane)	10	10	12
Rheem	3	13	12
York	10	7	5
Nordyne	3	4	4
Others	3	4	4

Source: Appliance Magazine, September 2001.[7]

The MHF market is principally shared by two manufacturers: York (Coleman) and Nordyne. Although Carrier and Trane have some models that can be installed in mobile homes and that comply with American National Standards Institute (ANSI) requirements, they are not dedicated systems (i.e., they are converted from mainstream models).

In the cast-iron boiler market, Burnham and Weil-McLain are the main manufacturers. In the steel market, Burnham competes with Thermo Dynamics and Axeman-Anderson. In the copper boiler market, the major manufacturers are Lochinvar, Waterpik, and Raypak. In addition to these manufacturers, there are a number of smaller regional manufacturers, but consolidation in this industry has been occurring over the last several years.

Sealed-combustion boilers with integrated water-heating are made by Burnham America Boiler Company and Trianco-Heatmaker, Inc.

Manufacturers of complete water-heater/fancoil combination units are Apollo HydroHeat & Cooling, First Company, and Lennox Industries Inc. Air handlers designed explicitly for use in combination systems are made by First Company, Goodman, SunTherm Heating Products, and Thermo Products Inc. Air handlers and/or coils that can be matched with water heaters to make up a combination system are made by Advanced Distributor Products, AllStyle Coil Company, Colmac Coil Manufacturing, and Williams Furnace Company. Water heaters are made by American Water Heater Company, A.O. Smith, Bradford White, Rheem Water Heater, and State Industries, Inc.

The blower-motor supplier market for residential furnaces (PSC motors) has large unit sales volumes. Approximately 3,000,000 units per year are sold to original equipment manufacturers, and approximately 8,000,000 units per year are sold to the aftermarket. Three major manufacturers are General Electric, Emerson Electric, and A.O. Smith; minor players in this market include Tecumseh, Regal-Beloit, WEG Electric Motor Corporation, and Toshiba International (Table 3.4.3).

More-efficient electronically commutating motors (ECMs) are used in high-efficiency furnaces. Approximately 50,000 to 250,000 units per year are sold to original equipment manufacturers. General Electric is a major manufacturer in this market, followed by Emerson Electric, Tecumseh and Rockwell Automation.

Table 3.4.3 Approximate Manufacturer Market Shares for Blower Motors, 2002 (%)

Manufacturer	PSC Blower Motor	ECM Blower Motor*
A.O. Smith	20-25	0
Baldor Electric	<1	0
Emerson Motors	20-25	<10
Tecumseh	10-15	<1
General Electric	35-40	>90
Regal-Beloit	6	0
Rockwell Automation	0	<1
Toshiba International Corp	<1	0
WEG Electric Motor Corp.	2	0
Others	<3	0

* The motor sizes considered are 1/3 and 1/2 hp

3.4.3 Distribution Channels

Two different markets exist for heating systems: new construction and replacements. Within each product class, the share of replacements in total sales ranges from around 70 percent for non-weatherized gas furnaces to over 90 percent for boilers.

In the new construction market, the home builder has a much stronger influence than the homeowner, who typically has little choice in what kind of system is installed. The new construction market tends to be a low-cost, low-efficiency market, as the decision-makers are not the beneficiary of the system installed. In the replacement market, on the other hand, the home owner is very influential. Replacements "in kind" (replacing a unit with similar or identical equipment) are common; however, premium products are more commonly sold in this market.

Most residential central heating equipment passes through a two-step distribution chain:

1) manufacturer to wholesaler (sometimes called distributor), and 2) wholesaler to contractor. One manufacturer, the only known exception, uses a one-step distribution chain (manufacturer to contractor). Several large retailers are trying to step between wholesalers and contractors, but most experts do not expect the trend to change the distribution chain significantly in the near term.

Roughly two dozen equipment manufacturers, several hundred wholesalers, and more than 30,000 contractors operate in the United States.

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